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THE UNUSUAL WEATHER AND CIRCULATION OF THE 1948-49 WINTER

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INTRODUCTION

The 1948–49 winter season was characterized by marked extremes of weather in different parts of the world. Most important, perhaps, was the severe and prolonged drought which seriously hampered postwar economic recovery in southern Europe. In addition, record amounts of rainfall were recorded in the Hawaiian Islands, extreme cold prevailed in Alaska and western Canada, unusually mild weather was experienced in western Europe and Mexico, and abnormal storminess persistently recurred in most of the Soviet Union. But the most spectacular weather of all occurred in the United States, where blizzards in the Great Plains and Rocky Mountain regions, freezes and snow in California, Arizona, and Texas, and ice storms in the midwest set new records for duration, frequency, and intensity and necessitated use of air lift and bulldozer tactics to save starving and freezing livestock.

Figure 1 shows that this winter's temperatures averaged as much as 10° F. below the seasonal normal in the western half of the United States and as much as 8° F. above normal in the eastern half of the country, while precipitation exceeded the normal amount nearly everywhere except in the Northwest and Southeast. This general pattern of weather anomalies first became evident at the end of October, slowly intensified during November and December, reached its most extreme state during January, and gradually abated during February and March. Not since the winter of 1889–90 has there been such a prolonged period of cold weather in the West and warm weather in the East. Although individual winter months have been more extreme, mean temperatures for this season as a whole were the lowest of record in at least one station in every State west of the Continental Divide and the highest of record at Blue Hill (and probably other places) in New England.[1]

The question naturally arises: "Was there any logical connection between the exceptional winter weather in the United States and the aberrations of weather in the rest of the world?" In order to demonstrate that such an interrelationship actually did exist, an attempt will be made to show, first, that the observed anomalies of weather were closely associated with equally well-marked and persistent anomalies of the general circulation, and, second, that many features of the observed circulation evolved in an orderly fashion consistent in part with known physical principles.

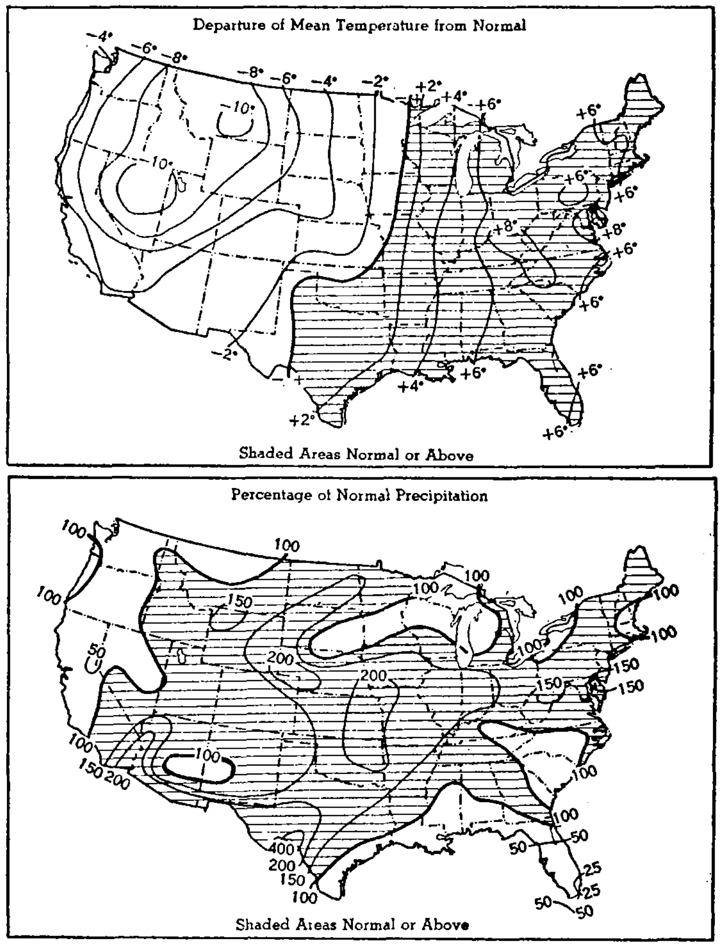


FIGURE 1.—Charts showing average temperature and precipitation anomalies for the winter of 1948–49 (December through February). Temperature departure from normal is shown in degrees Fahrenheit. (From the "Weekly Weather and Crop Bulletin" for the week ending March 8, 1949.)

[1] Many interesting details of this winter's weather in the United States are described in the following U. S. Weather Bureau publications: "Monthly Weather Review" (for each month of the winter), "Weekly Weather and Crop Bulletin" (particularly the issue for the week ending February 8, 1949), and "Daily Weather Map" (particularly analyzed series No. 42 by L. Kiviat issued April 12 and 13, 1949). Also noteworthy is the report on "Winter Weather of 1948-49 at the Blue Hill Meteorological Observatory of Harvard University, Milton, Massachusetts" and the following publications of the Amateur Weathermen of America: "Weatherwatch" (for each month of the winter) and "Weatherwise" (especially articles by Cameron, Klein, and Sorenson in vol. 2, No. 2, April 1949). Mean monthly anomalies of temperature and precipitation at selected stations throughout the world can be found in the U. S. Weather Bureau publication: "Monthly Climatic Data for World."

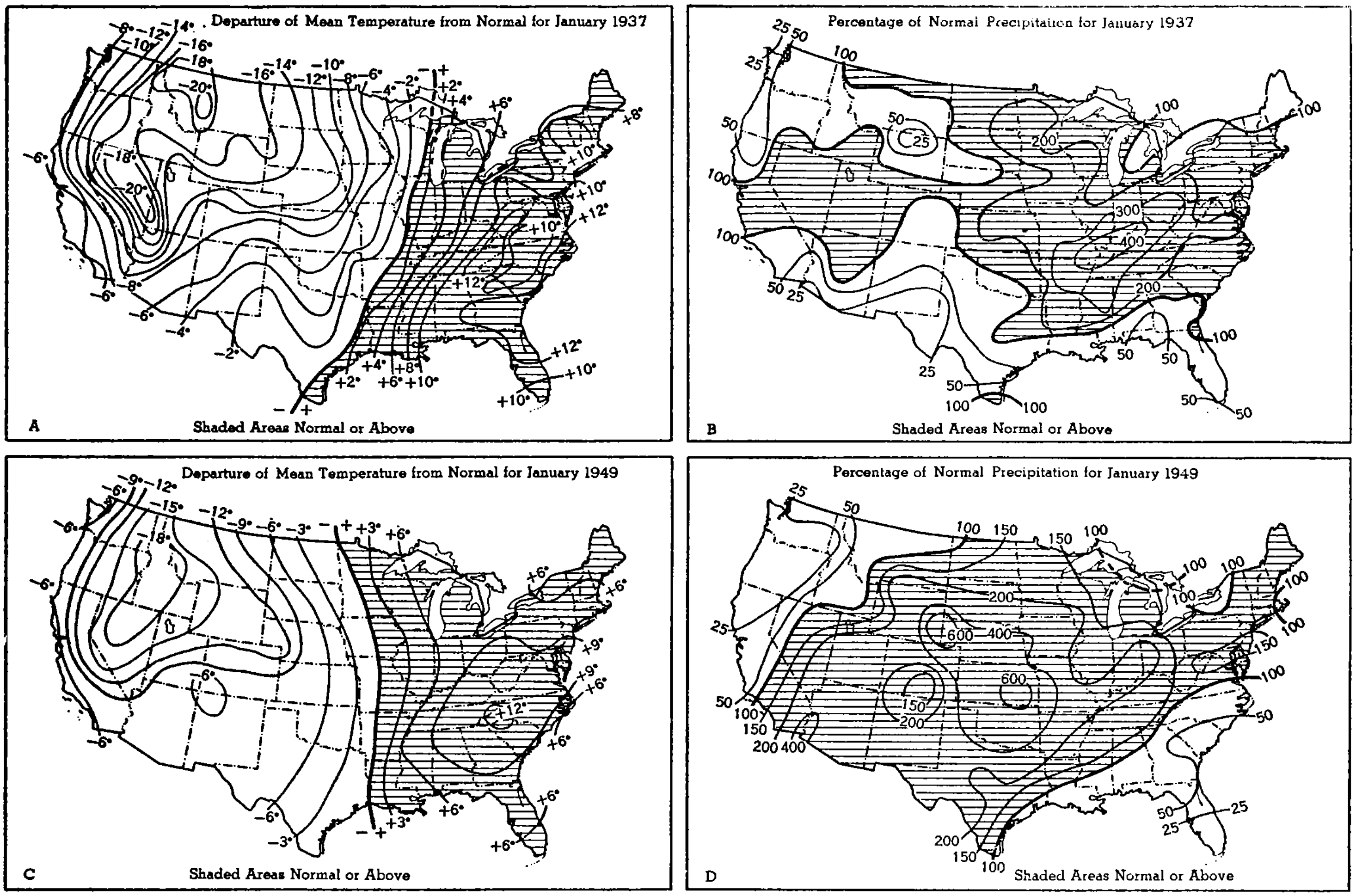


Figure 2.—Charts showing the similarities between the average temperature and precipitation anomalies for January 1937 and January 1949. Temperature departure from normal is shown in degrees Fahrenheit. (From the "Weekly Weather and Crop Bulletin" for the first week of February 1937 and 1949.)

Relation Between Weather and Circulation

Figure 2 gives the surface temperature anomaly and the percentage of normal precipitation observed in the United States for the month of January 1949, when this winter's weather contrasts were most extreme, and also for the month of January 1937, a remarkably close analogue. Both months were characterized by severe cold in the West, with monthly mean departures as great as 18°–20° F. below normal in the Great Basin, and by abnormal warmth in the East, where the greatest anomaly was plus 12°–14° F. in the Carolinas. The similarity in precipitation is not quite as marked, but during both months less than half of the normal precipitation fell in the Northwest and Southeast and from 2 to 4 times the normal amount in central parts of the country. This general weather regime persisted for 4 months this winter but for only 6 weeks in 1937.

The monthly mean sea level pressure distribution over most of the western hemisphere was remarkably similar during both January 1937 and January 1949, as illustrated by figure 3. The pressure profiles in the inset boxes of this figure show that both months were marked by an excess of mass (above-normal pressures in shaded area) at middle latitudes and a deficit of mass at both high and low latitudes. As a result easterly wind components were stronger than normal from approximately 20° to 45° N. latitude and were instrumental in the production of heavy orographic rain in the Hawaiian Islands, warm moist maritime weather in the eastern United States and Mexico, and dry continental conditions on the west coast of the United States (and in southern Europe in January 1949). It is noteworthy that both this winter and the abnormal winter of 1946–47 described by Namias [1] were characterized by a low zonal index; but this was brought about by a northward displacement of the middle-latitude westerlies this winter, in contrast to their shift southward during the winter of 1946–47 when conditions were similar to the typical low index conditions described by Willett [2].

Other striking features of both mean sea level charts in figure 3 are first, the northward displacement of the Great Basin and eastern Pacific Highs, which diminished the frequency of warm dry foehn winds east of the continental divide and produced cold northeasterly winds instead in the western United States (as in western Europe two winters ago); and second, the westward intrusion of the Bermuda High, with its attendant moist maritime tropical air, into the eastern United States. The circulation features in the entire Pacific area were markedly similar during both January 1937 and January 1949, with the Aleutian Low deeper and farther northwest than normal, the Eastern Pacific High stronger and farther north than normal, and an anomalous low-latitude trough near the Hawaiian Islands. This pattern closely resembles the ideal pressure pattern for general heavy rain in the Hawaiian Islands given by Solot and Haggard [3], and such

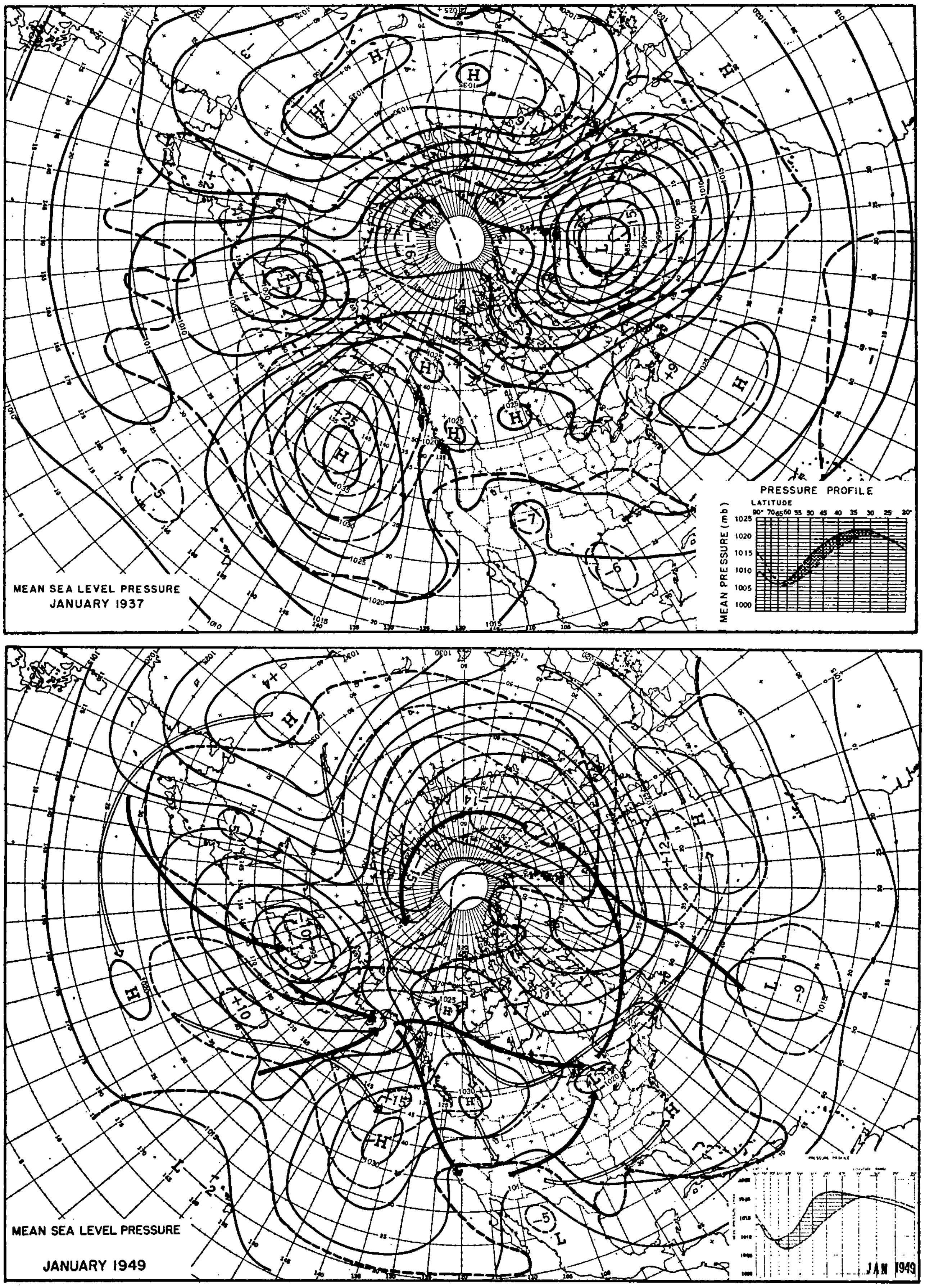


FIGURE 3.—Mean sea level charts for January 1937 and January 1949 showing isobars at 5-mb. intervals (solid lines) and pressure departure from normal at 5-mb. intervals (dashed lines, with zero isopleth heavier). Anomaly centers and isobars are labeled in millibars. Solid arrowhead curves represent idealized mean cyclone tracks and the open arrowhead curves the idealized mean anticyclone tracks. Inset shows observed Western Hemisphere pressure profile (from 20° to 90° N. latitude) as a solid curve and normal pressure profile as a dashed curve with excess anomalies shaded.

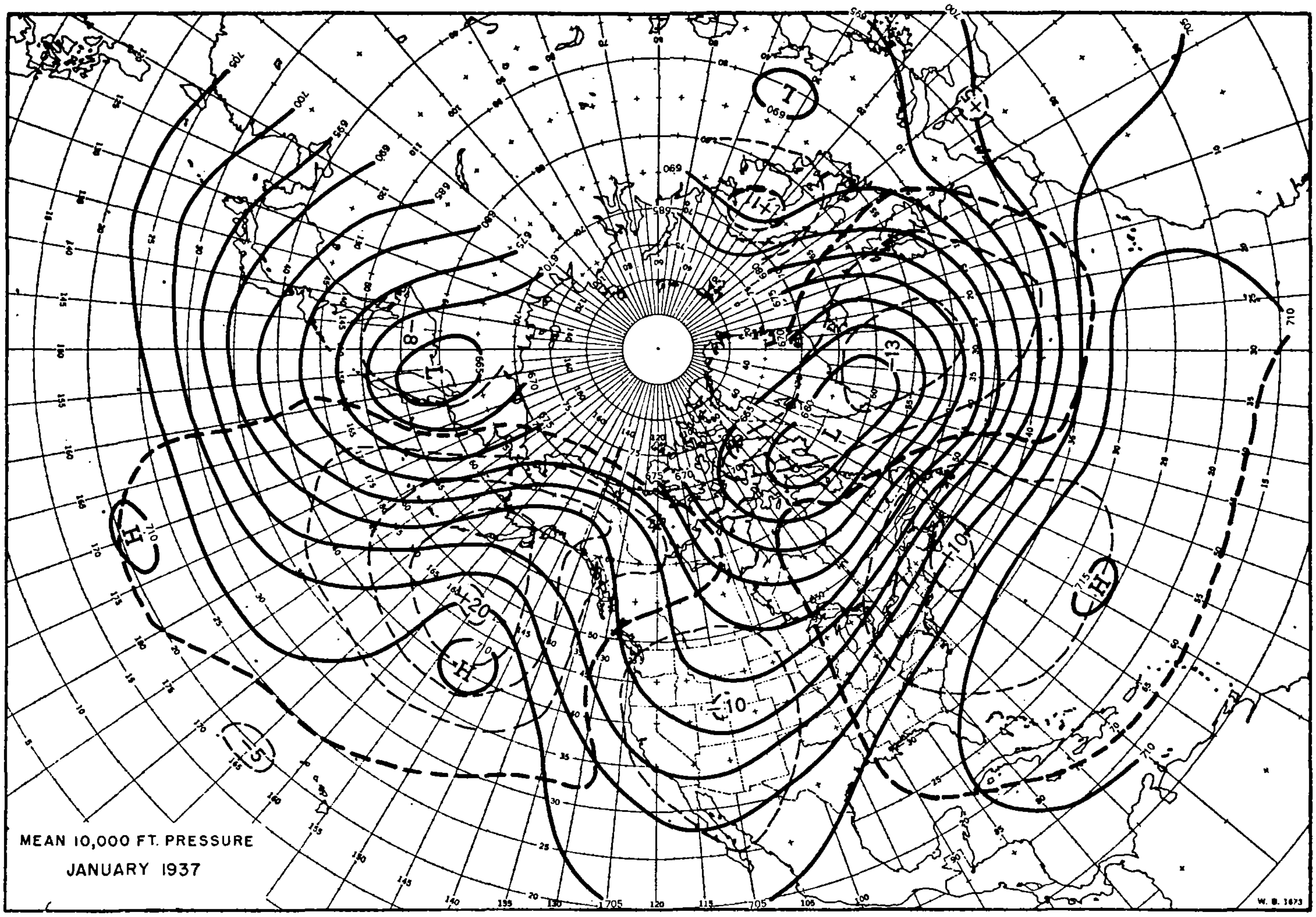


Figure 4.—Monthly mean 10,000-foot pressure chart for January 1937. Isobars at 5-mb. intervals are shown by solid lines and 10,000-foot pressure departure from normal at 5-mb. intervals by dashed lines with the zero isopleth heavier. Anomaly centers and isobars are labeled in millibars.

rains actually did fall during both months illustrated here. The circulation patterns were quite different, however, in the eastern Atlantic and Europe, where anticyclonic conditions and drought this winter contrasted sharply with cyclonic conditions and floods in January 1937.[2]

The sea level map for January 1949 (fig. 3) also includes the principal mean cyclone and anticyclone tracks for the month. They were drawn in schematic fashion along the mean trough and ridge lines with the aid of the individual tracks published in the Monthly Weather Review (January 1949) and the 700-mb. mean steering pattern (fig. 9a), and they help to explain the observed weather. Cyclones and upper-air troughs from the Gulf of Alaska moved weakly down the west coast of North America and deepened in the southwestern United States, behavior similar to that of "type A" disturbances [4]. As the storms curved northeastward they pulled moist tropical air from the Gulf of Mexico far northward and, in some cases, northwestward, to overrun cold polar air and produce blizzards in the northern Plains, ice storms in the southern Plains, heavy rains in the Mississippi and Ohio Valleys, and mild weather in the eastern United States, where the tropical air reached the ground. After leaving the United States the storms continued to move northeastward across the North Atlantic and northern Eurasia along a trajectory unusually far to the north so that storminess and precipitation were virtually absent in southern Europe. The cold polar anticyclones which normally move southeastward across North America from Alaska toward Bermuda (Bowie and Weightman [5]) either skirted the northern border of the United States without penetrating the country appreciably or moved due southward into the Plateau (where the Basin High was made up by cold continental instead of warm Pacific anticyclones) and warmed up before swinging eastward along the Gulf coast.

Of greater importance, perhaps, than the mean sea level charts in explaining the observed weather anomalies are the mean 10,000-foot map for the month of January 1937 (fig. 4) and the mean 700-mb. map for the month of January 1949 (fig. 9a). Both maps are characterized by a deep trough in the western United States and a strong ridge in the East, a complete reversal of the normal January circulation pattern (Namias and Smith [6]). As noted in previous studies of the dependence of temperature upon the upper air circulation (Namias [7] and Martin [8]), the area of subnormal surface temperature (fig. 2) has cyclonic curvature and below normal heights or pressure aloft, while the area of anticyclonic curvature and above-normal 700-mb. height or 10,000-foot pressure is situated directly over the area of abnormal surface warmth. The observed precipitation anomaly (figs. 2 and 9c) closely resembles the author's schematic model for winter precipitation (Klein [9]), with heavy precipitation oriented from southwest to northeast along and ahead of the 700-mb. trough in southwesterly flow

[2] There is an interesting suggestion in these facts that the weather in most of the United States is more closely related to the general circulation in the Pacific than in the Atlantic. This hypothesis is supported by unpublished results recently obtained by D. E. Martin of the Extended Forecast Section of the U. S. Weather Bureau which show that the five-day mean temperature anomaly at most stations in the United States is highly correlated with the 700-mb. height anomaly in the Gulf of Alaska region.

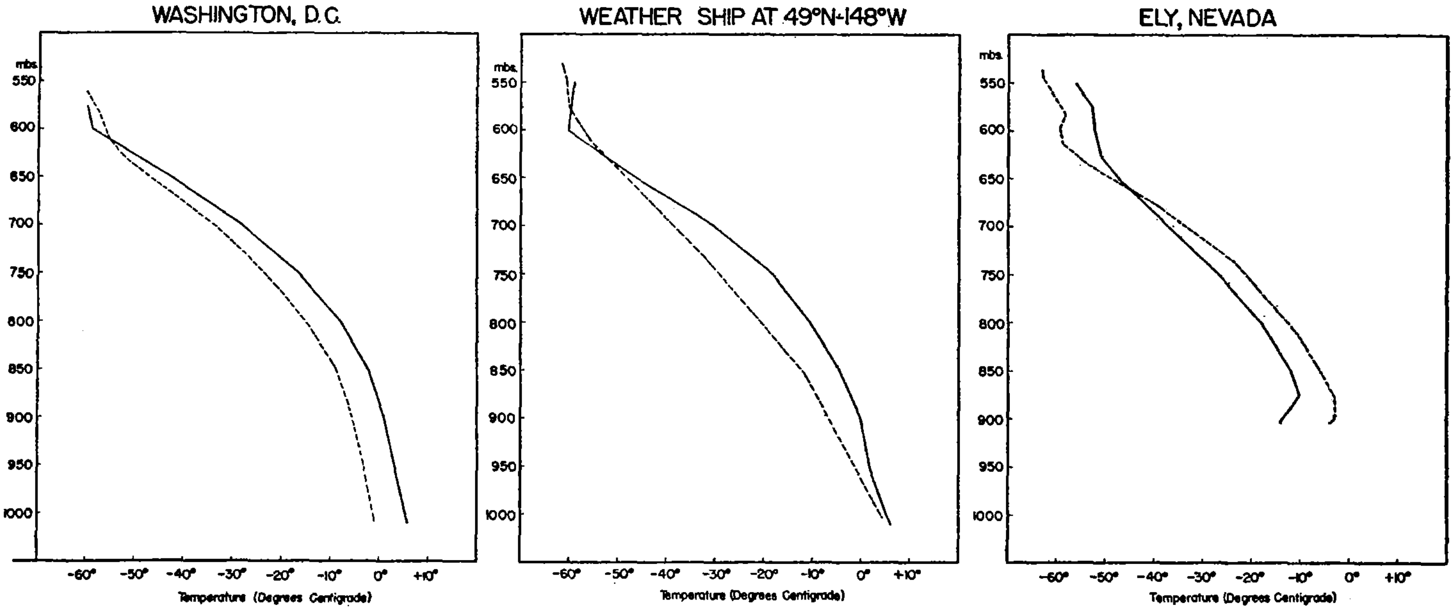


FIGURE 5.—Monthly mean soundings for January 1949 made at Washington, D. C., Ely, Nev., and aboard the United States Coast Guard Cutter *Chautauqua* at 49° N., 148° W. The normal January soundings are shown as dashed lines.

and confluence aloft, and with light precipitation in the rear of the trough in the Northwest and near the High center in the Southeast.

These relationships between surface weather and 700-mb. circulation can be used to explain the temperature and precipitation anomalies observed in other months of this winter and in other parts of the world. To illustrate this, the monthly mean 700-mb. chart, the surface temperature and precipitation anomalies, and the thickness anomaly of the layer between 1,000- and 700-mb.[3] observed during each month from October 1948 to March 1949 have been reproduced from the files of the Extended Forecast Section of the U. S. Weather Bureau in figures 6 to 11. For the most part the regions of below-normal temperature (or thickness) coincide with the areas of below-normal 700-mb. height, as, for example in the western part of North America during November, December, January, and February; while the regions of above-normal temperature lie in close proximity to the areas of above-normal 700-mb. height, as in most of Europe from October through February. The anomaly of gradient air flow relative to the normal is also important in determining surface temperature and precipitation. For example, above-normal temperatures occurred in regions of below-normal heights because of strong southerly winds relative to the normal in Mexico during October, January, and February, and in the Mississippi Valley during November and December; while below-normal temperatures occurred in regions of above-normal heights because of northerly wind components in western Canada and northwestern United States during January and in western Europe and Central Siberia during March. Likewise, stronger-than-normal westerly wind components produced heavy precipitation along the northwest coast of the United States but created a rain-shadow effect east of the mountains during November, December, and February. Finally, the effect of 700-mb. contour curvature on precipitation in the western part of the United States should be mentioned (Smith [11]). For example, heavy precipitation in the Southwest during October, December, and January was associated with cyclonic curvature aloft, while light precipitation occurred during November with anticyclonic curvature aloft.

In figure 5 are shown the January 1949 mean soundings made at Washington, D. C., Ely, Nev., and aboard the U. S. Coast Guard Cutter *Chautauqua* located at 49° N., 148° W., and the normal January soundings for these points. For Ely and Washington, the observed soundings were plotted from data published in the MONTHLY WEATHER REVIEW for January 1949, and the normal soundings were obtained from data of Ratner [12]; for the weather ship the observed sounding was based on unpublished data of the United States Weather Bureau, and the normal sounding was constructed from values interpolated among the isobers and isotherms on the "Normal Weather Maps Northern Hemisphere Upper Level". At Ely, where a trough existed at the 700-mb. level, temperatures were below normal not only at the surface but at every level of the troposphere. At Washington and at the position of the U. S. *Chautauqua*, in the 700-mb. ridges, temperatures were above normal throughout the entire troposphere. As expected from previous studies of cold lows and warm highs (for example, Rossby and Willett [13]) the tropopause and stratosphere were lower and warmer than normal at Ely and higher and colder than normal at Washington and the ship. It is thus apparent that we are dealing with large scale and persistent anomalies of the general circulation which appeared throughout the entire observed atmosphere of the Northern Hemisphere. A complete explanation of this phenomenon in terms of all possible terrestrial and extra-terrestrial causes is beyond the scope of this paper. Instead the observed evolution of the circulation pattern is described and a possible physical explanation suggested.

EVOLUTION OF THE OBSERVED CIRCULATION

In the discussion to follow an attempt is made to apply kinematic and physical principles to troughs and ridges on monthly mean 700-mb. charts. Only the mean charts for calendar months are reproduced here (figs. 6 to 11, part a), but mean charts for monthly periods from each mid-month to the next mid-month with kinematic computations based on 10-day height tendencies centered around each mean were also used to confirm the continuity ascribed to the principal circulation features. The propriety of applying physical principles to monthly

[3] In view of the high correlation which exists between surface temperature and mean virtual temperature of the layer between the surface and 10,000 feet (Rowe [10]), the 1,000 to 700-mb. thickness anomaly has been used instead of the surface temperature anomaly in regions outside the United States where class limits for surface temperature are not available.

mean charts is not discussed in this paper; some theoretical justification was presented by Clapp [14], and successful empirical examples were described by Namias [15]. Principal reliance is placed on qualitative application of wave length principles (Rossby [16]) and constant absolute vorticity trajectories (Rossby [17]). These were previously applied to 5-day mean maps with considerable success—wave length by Namias and Clapp [18] and vorticity by Bortman [19]. As far as possible, points of inflection with little shear on the axes of broad, fast, well-defined currents were selected for construction of vorticity trajectories. Normal fields of divergence (Namias and Clapp [20]) and the time required by individual air particles to reach trough and ridge points were neglected in computing these trajectories. They were used primarily to give the stationary wave length, as suggested by Cressman [21] and Namias [15], and to indicate the general type of circulation developments favored downstream as a result of energy dispersion from an initial disturbance.

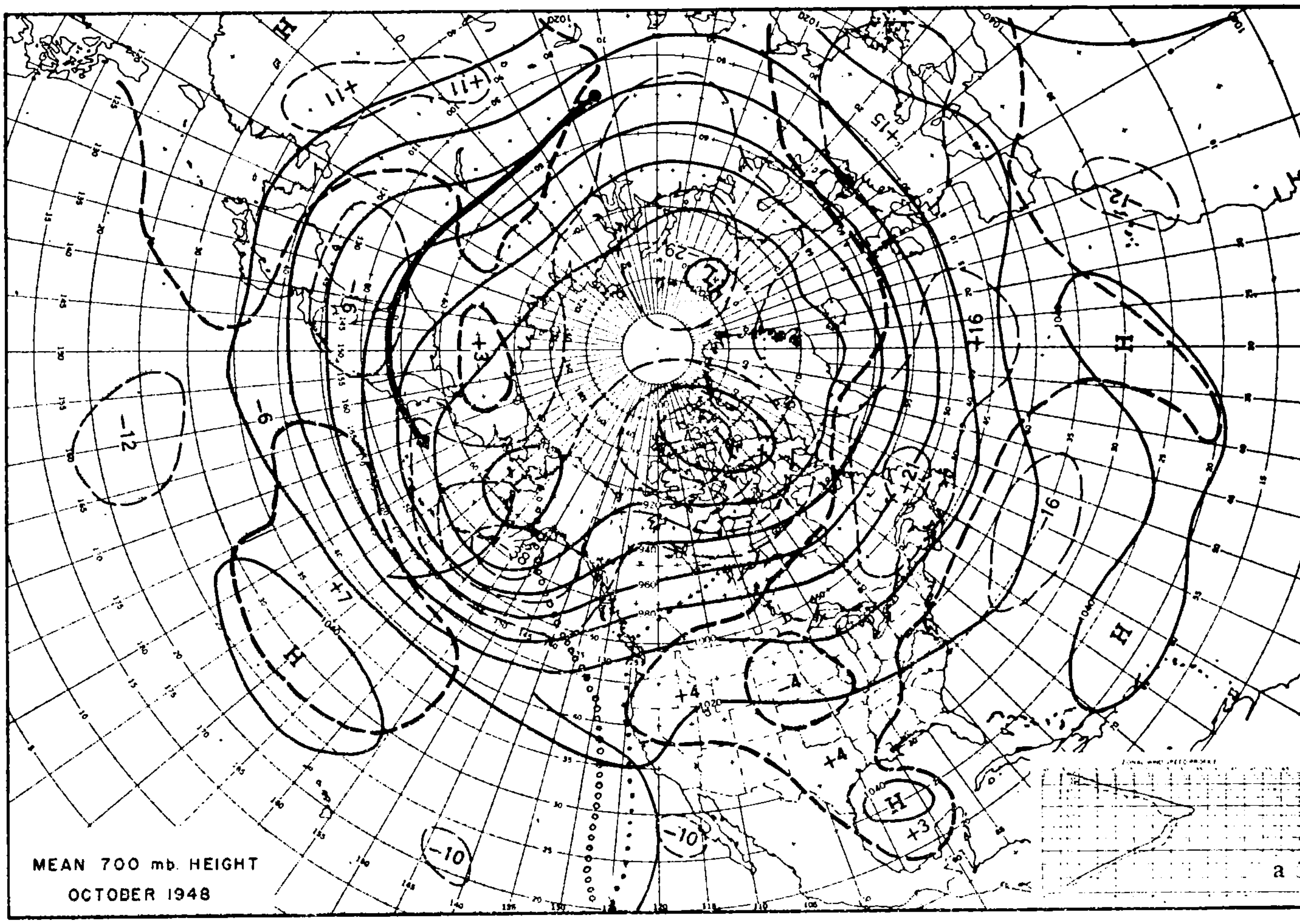
The first map in the series is the monthly mean 700-mb. chart for October 1948 (fig. 6a). In general the map presents a flat appearance without any extreme anomalies. The western hemisphere zonal wind speed profile (inset) shows that during October there was a well defined mean jet stream [22] between 50° and 55° N. latitude, 5° north of the jet position on the normal profile (dashed). The line of dots along the west coast of North America gives the position of a monthly mean trough during August, the line of open circles shows the position of this same mean trough during the month of September, and the solid curves give the trough position during October. It can be seen that the entire trough retrograded from August to September, but the trough sheared in October, with the upper portion continuing to retrograde and the lower portion reversing its motion and starting eastward. As a result a Low was located directly north of a High in the central Pacific during October with a band of abnormally fast westerlies in between. Continued retrogression was favored for the trough in the north by the existence of an extremely long wave length between it and the next high latitude trough upstream in Europe. This wave length was considerably longer than the stationary wave length given by the vorticity trajectory computed from the mean southwesterly flow in Siberia (fig. 6a). Conditions were unfavorable for retrogression in the south, however, because of the presence of a low latitude trough in the western Pacific during October.

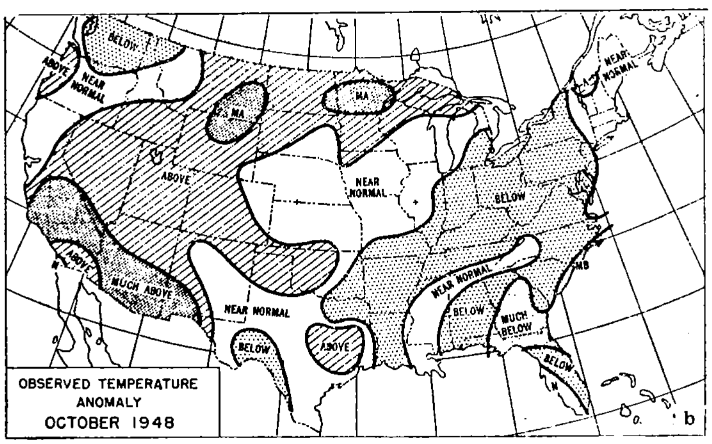
The monthly mean 700-mb. chart for November is reproduced in figure 7a. It shows that the flat circulation of the preceding month was replaced by a series of well-marked waves in the westerlies. As frequently happens on five-day mean maps (Willett [2]), this increase in amplitude was associated with a southward shift of the jet stream to a location between 40° and 45° N. latitude, 5° south of the normal and 10° south of the October position. It is possible that these changes were initiated by dynamic factors operating on the unusually fast westerly current set up in the central Pacific in October (and maintained during November) and tending to produce a trough to the lee of the Rocky Mountain range. The development of this "Divide trough" was favored by the presence of abnormally cold air off the West Coast during October and November (figs. 6d and 7d) and by the fact that a low-latitude trough, such as the one off California in October, normally tends to separate from its high latitude portion and build to higher latitudes subsequent to shearing (Namias and Clapp [18]).

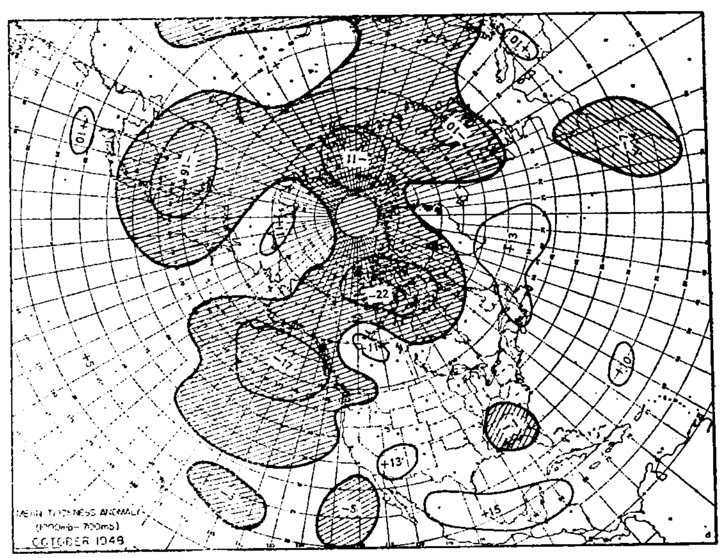
The development of the Bermuda ridge, Atlantic trough, and European ridge during November can then be explained by the rapid spread of energy downstream from the Divide trough, as shown by the vorticity trajectory computed from a point in Ohio (fig. 7a). The trough in Russia apparently had not yet been affected much by these developments, since it was still quite flat in November with smaller amplitude than the trough-ridge system upstream from it. A vorticity trajectory, computed from this system in the southwesterly flow west of Ireland had considerably greater amplitude (almost 10° of latitude) than the contours that it crosses in Europe on the mean 700-mb. chart for November, while a vorticity trajectory computed in the southwesterly flow ahead of the Russian trough gives a wave length across Siberia which is still considerably shorter than that which existed there in November. Two puzzling features of the November map in the Pacific are the positive anomaly north of the Hawaiian Islands and the closed low in the Gulf of Alaska. The former was important because it persisted for the entire winter season; the latter was important because it was associated with a large quantity of abnormally cold air in Alaska and western Canada (fig. 7d).

The next map in the series is that for December 1948 (fig. 8a). The mean jet stream remained essentially unchanged between 40° and 45° N. latitude. The upper portion of the Pacific trough continued its long period retrogression from its October position in the Gulf of Alaska and its November position in the Bering Sea, and joined the low-altitude trough off Japan to form a single strong full-latitude trough in the western Pacific. In part as a result of the dispersion of energy downstream from this trough, a strong full-latitude ridge with a tremendous positive anomaly of 530 feet developed in the east central Pacific, while trough conditions and below normal heights intensified over western North America. At the same time the Gulf of Alaska trough was forced eastward to the Alaskan coast by the short wave length between it and the trough in the Bering Sea in November, as indicated by the vorticity trajectory passing through the area (fig. 7a). As a result of these developments, negative heights and northerly wind components (relative-to-normal) produced an extreme thickness anomaly of −500 feet in the lowest 3 km. of the atmosphere in the Yukon (fig. 8d). In accordance with November's vorticity trajectory in the Atlantic, the circulation pattern increased its amplitude considerably in Eurasia, where larger anomalies of +400 feet and −550 feet appeared during December. In response to this increase in amplitude, both wave length and wind speed over Eurasia increased (Bortman [23]), and the Russian trough moved about 25° longitude to the east. As a result of this eastward motion and strengthened circulation, a vorticity trajectory originating in the strong northwesterly flow in Russia places a trough (at 54° N., 164° E.) just east of the position occupied by the Pacific trough in December, puts a crest in Alaska, and has greater amplitude than the contours observed in the Pacific in December. At the same time, a vorticity trajectory computed in the strong southwesterly flow south of the Aleutians cuts across three of the contours observed in the United States on the mean 700-mb. chart for December. The two trajectories approach each other and indicate a zone of confluence (Namias [24]) near James Bay.

The next map in the series is that for January 1949 (fig. 9a). It shows that the January jet stream was centered between 50° and 55° N. latitude, 5° north of







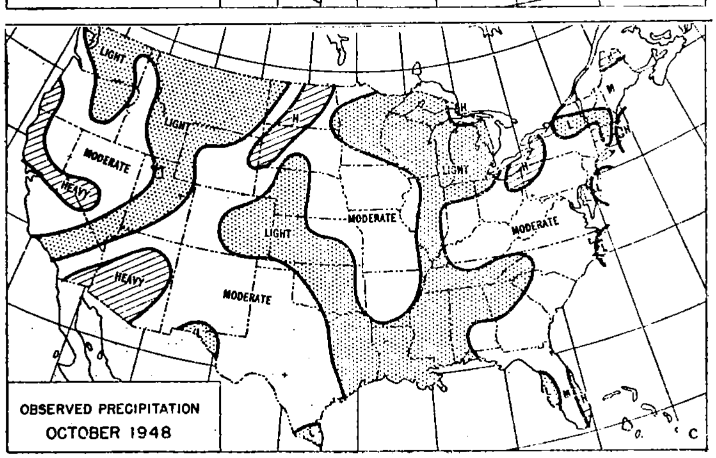


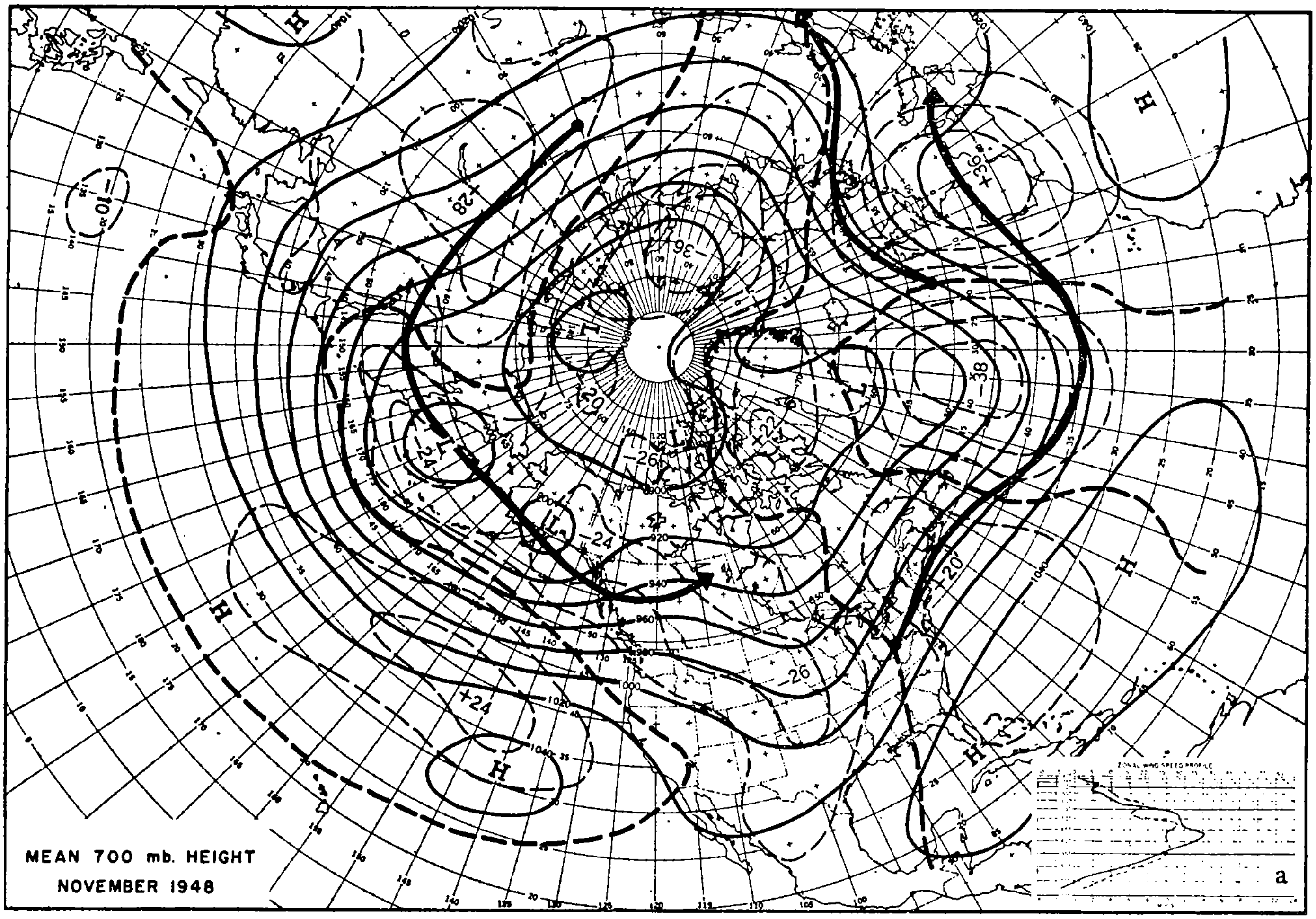
Figure 6.—Monthly mean charts for October 1948.

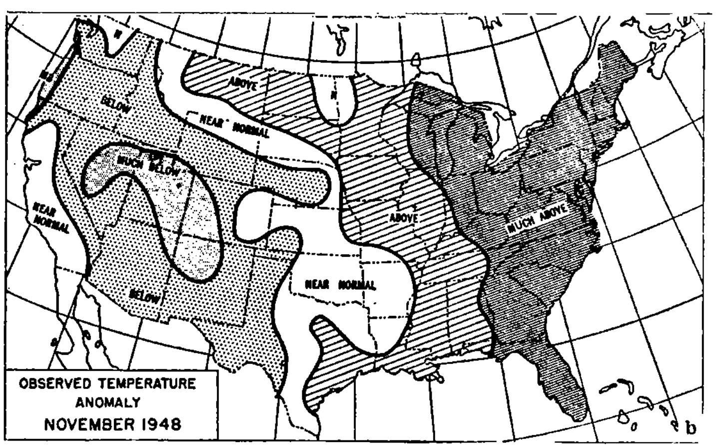
a. 700-mb. chart. Contours at 200-foot intervals are shown by solid thin lines, 700-mb. height departure from normal at 100-foot intervals by dashed lines with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Heavy arrowhead curve shows vorticity trajectory. Mean positions of Pacific trough during August, September, and October 1948 are shown by dotted line, line of open circles, and solid line, respectively. Inset: Solid curve shows observed geostrophic zonal wind speed components in meters per second for the Western Hemisphere from 20° to 90° N. latitude; dashed line represents normal wind profile.

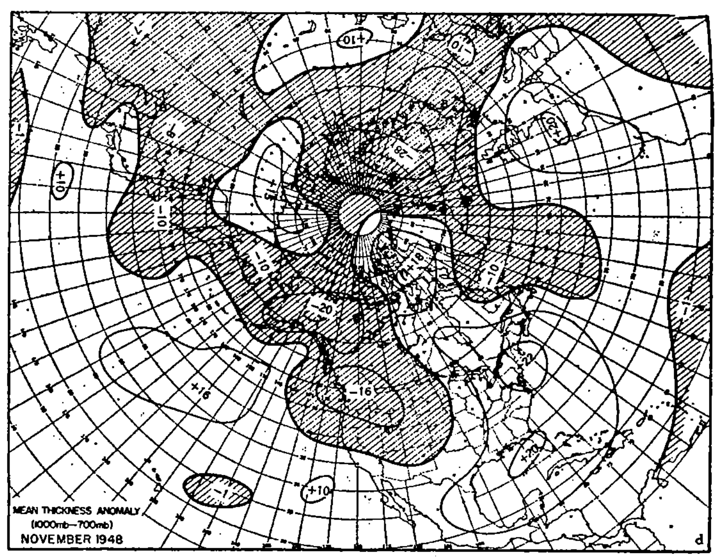
b. Surface temperature anomaly. The classes above, below, and near normal occur on the average one-fourth of the time, while much above and much below each occur normally one-eighth of the time.

c. Precipitation anomaly. The classes light, moderate, and heavy occur on the average one-third of the time and therefore have equal probability of occurrence.

d. Thickness anomaly for the layer between 1,000- and 700-mbs. Isopleths are drawn at 100-foot intervals with the zero isopleth heavier, and centers are labeled in tens of feet. Negative values are shaded.







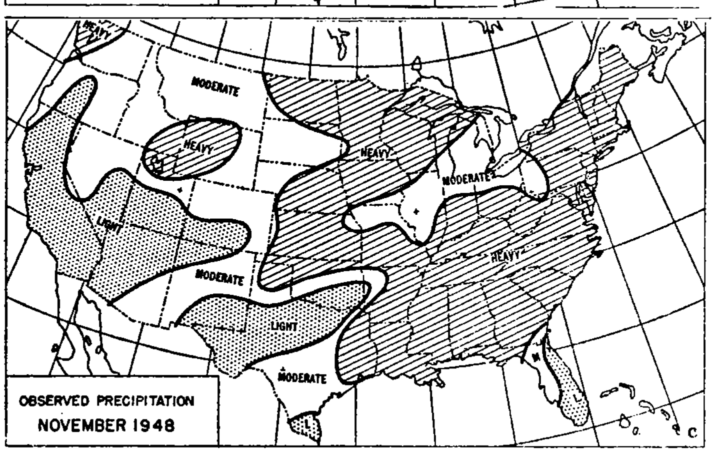


FIGURE 7.—Monthly mean charts for November 1948.

a. 700-mb. chart. Contours at 200-foot intervals are shown by solid thin lines, 700-mb. hight departure from normal at 100-foot intervals by dashed lines with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Heavy arrowhead curve shows vorticity trajectory. Inset: Solid curve shows observed geostrophic zonal wind speed components in meters per second for the Western Hemisphere from 20° to 90° N. latitude; dashed line represents normal wind profile.

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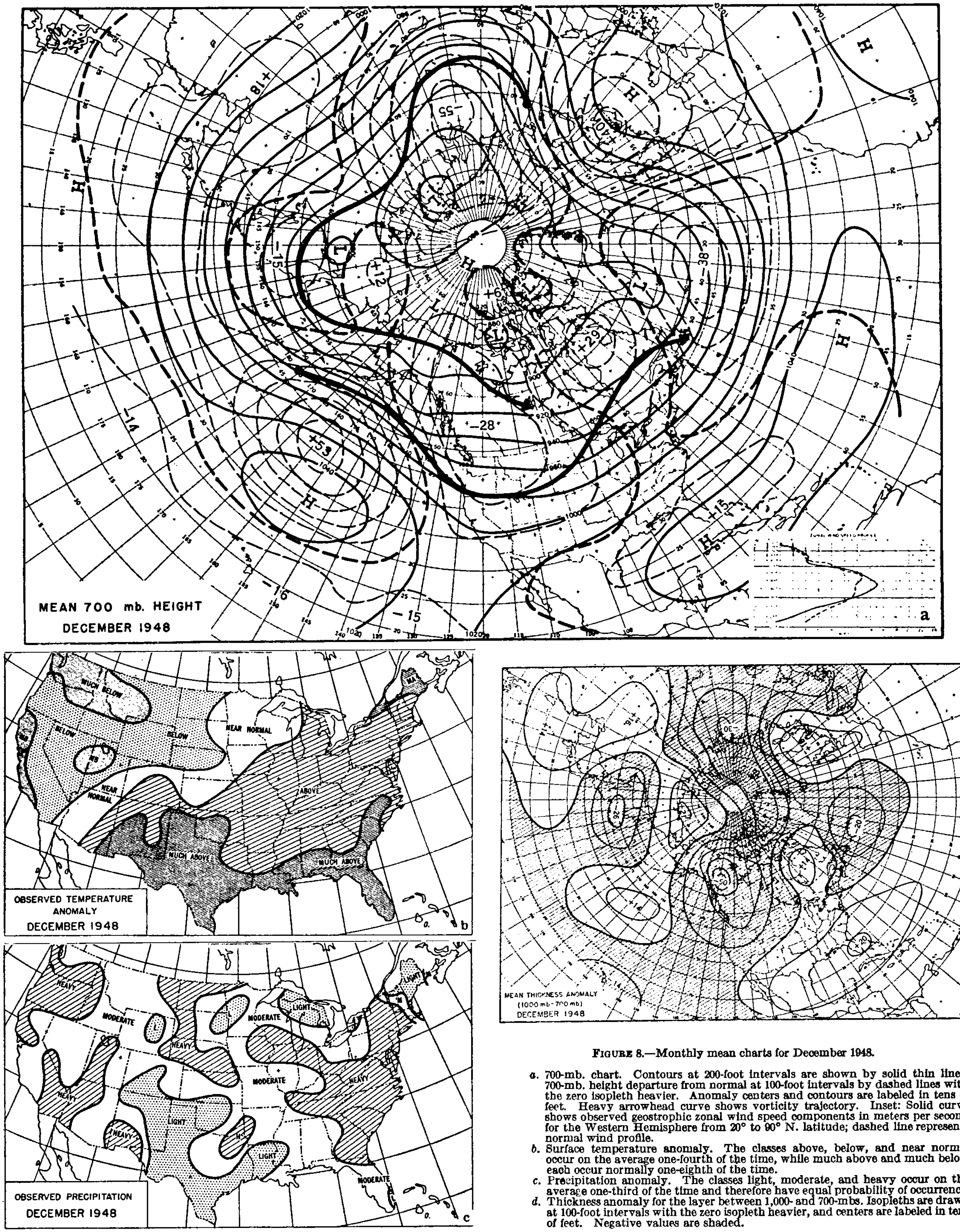

Figure 8.—Monthly mean charts for December 1948.

a. 700-mb. chart. Contours at 200-foot intervals are shown by solid thin lines, 700-mb. height departure from normal at 100-foot intervals by dashed lines with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Heavy arrowhead curve shows vorticity trajectory. Inset: Solid curve shows observed geostrophic zonal wind speed components in meters per second for the Western Hemisphere from 20° to 90° N. latitude; dashed line represents normal wind profile.

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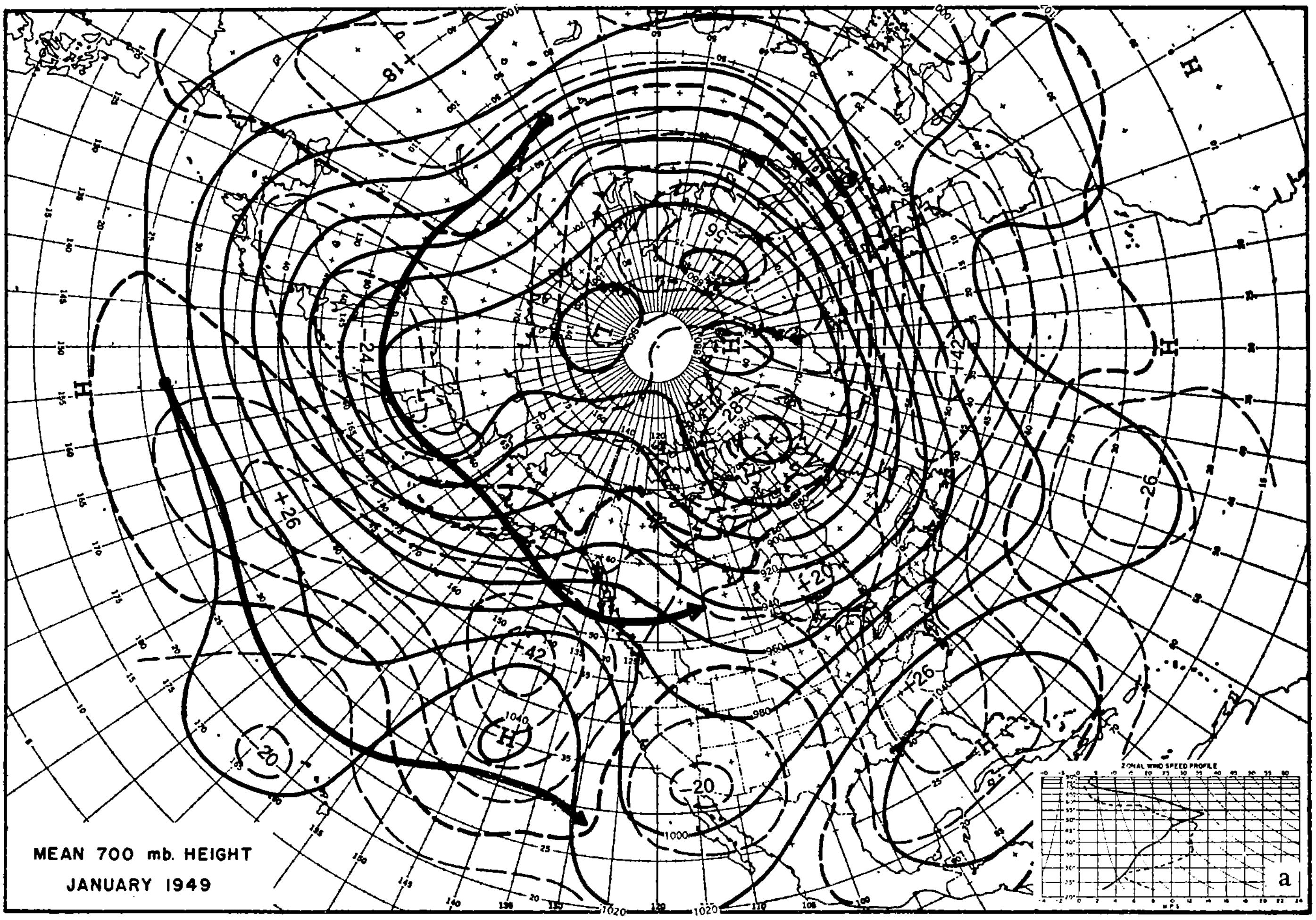

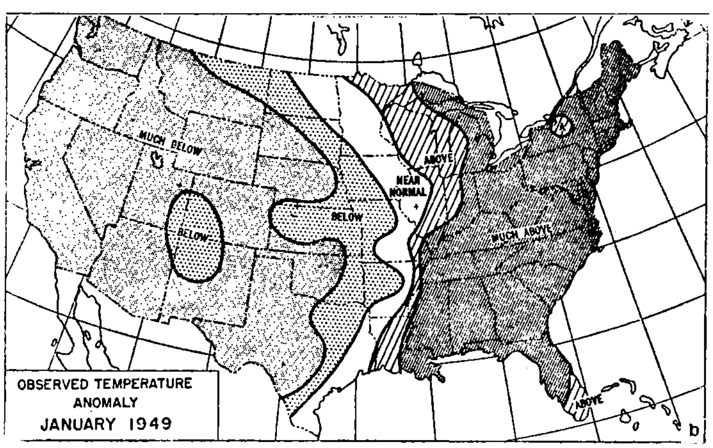

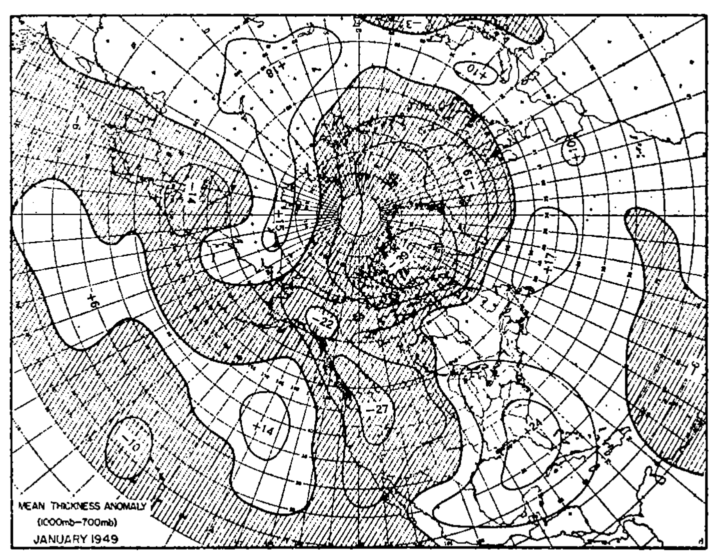

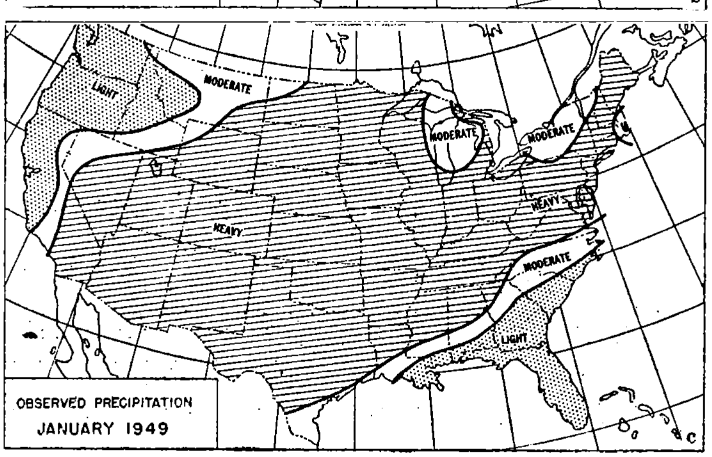

Figure 9.—Monthly mean charts for January 1949.

a. 700-mb. chart. Contours at 200-foot intervals are shown by solid thin lines, 700-mb. height departure from normal at 100-ft. intervals by dashed lines with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Heavy arrowhead curve shows vorticity trajectory. Inset: Solid curve shows observed geostrophic zonal wind speed components in meters per second for the Western Hemisphere from 20° to 90° N. lat.; dashed line represents normal wind profile.

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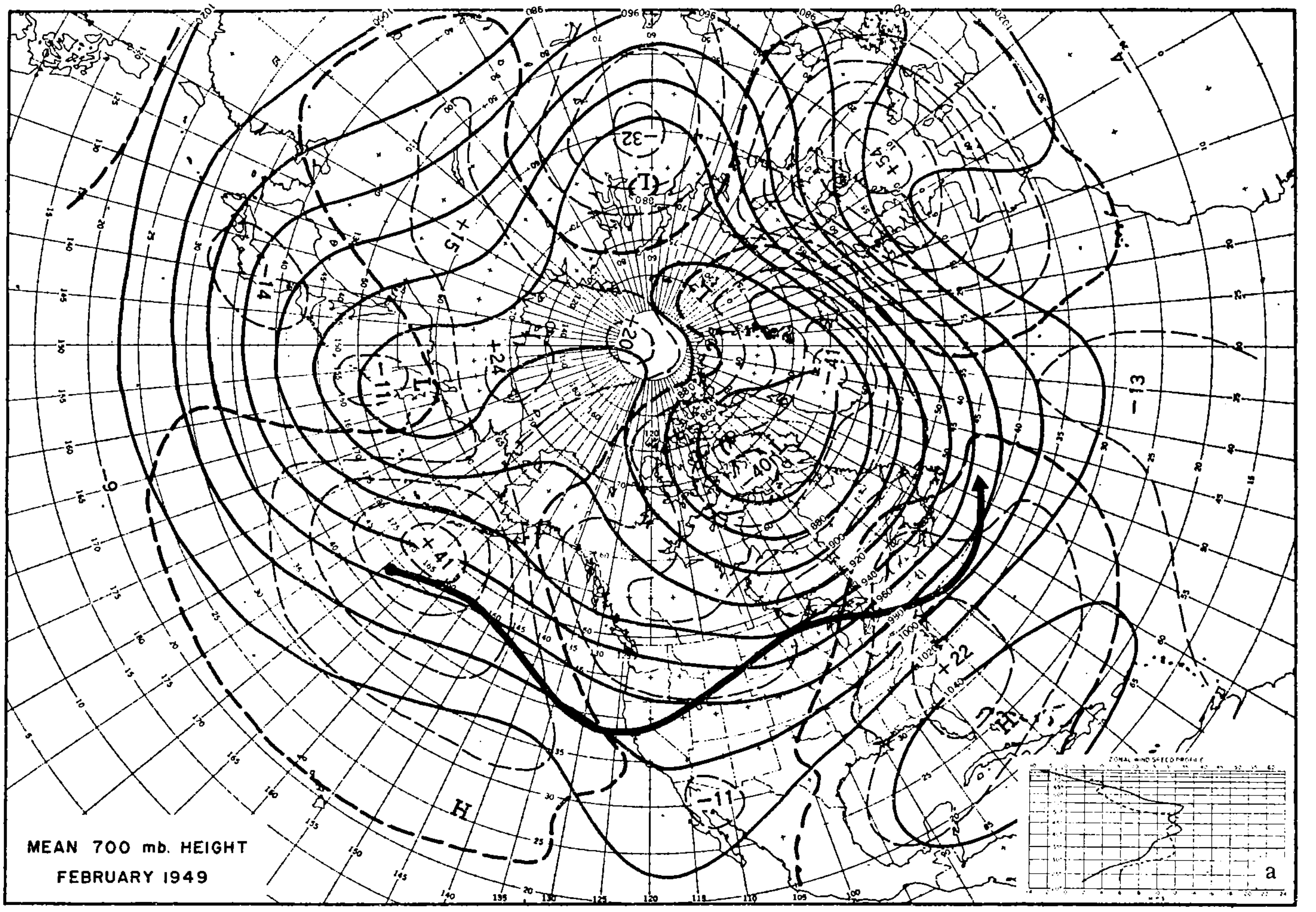
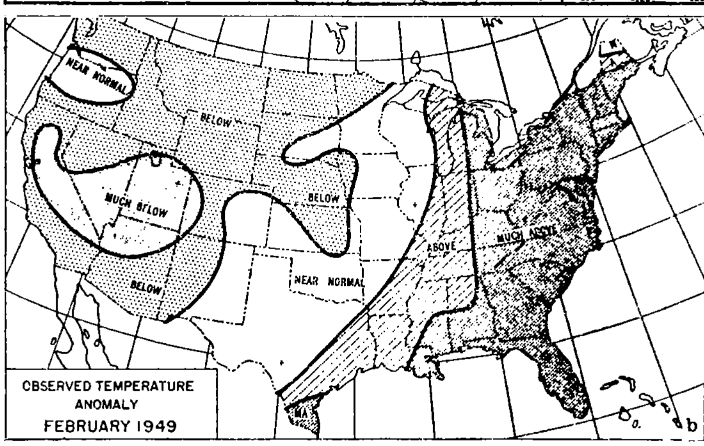
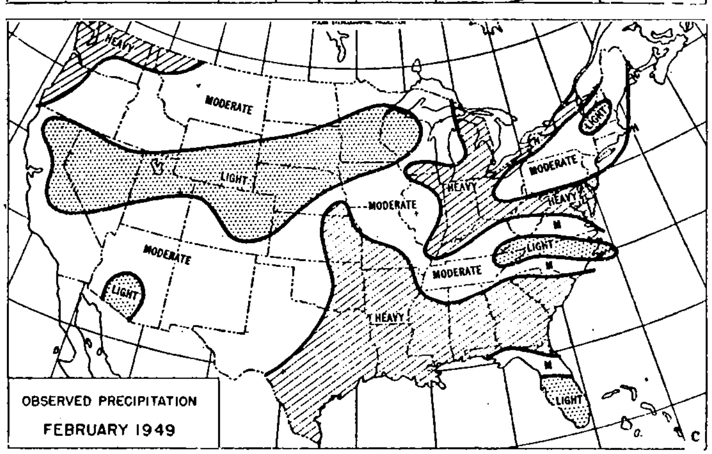






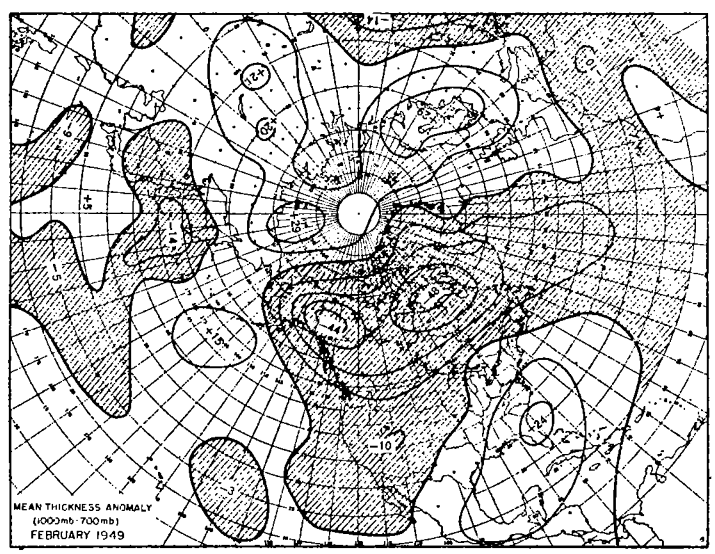


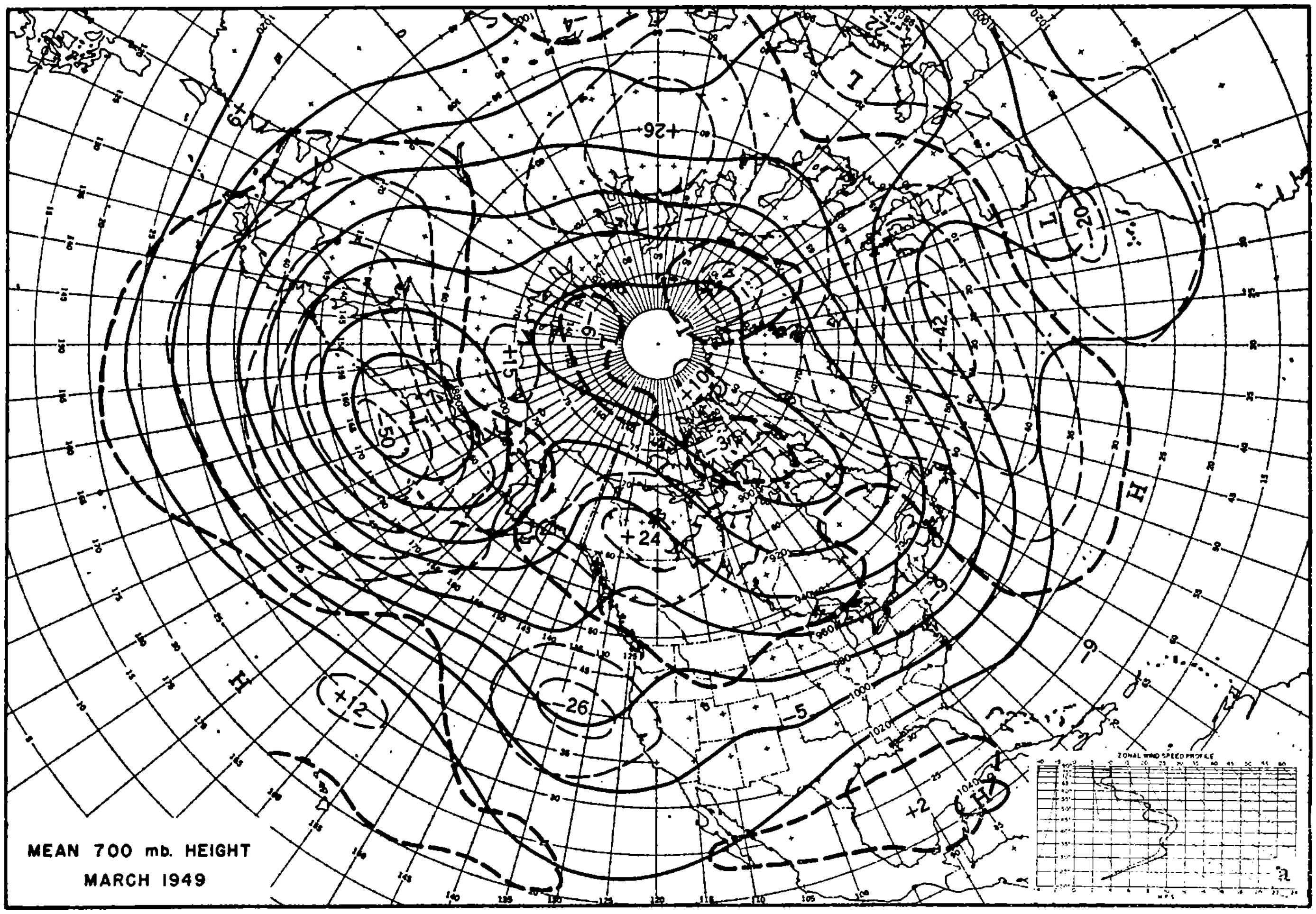
FIGURE 10.—Monthly mean charts for February 1949.

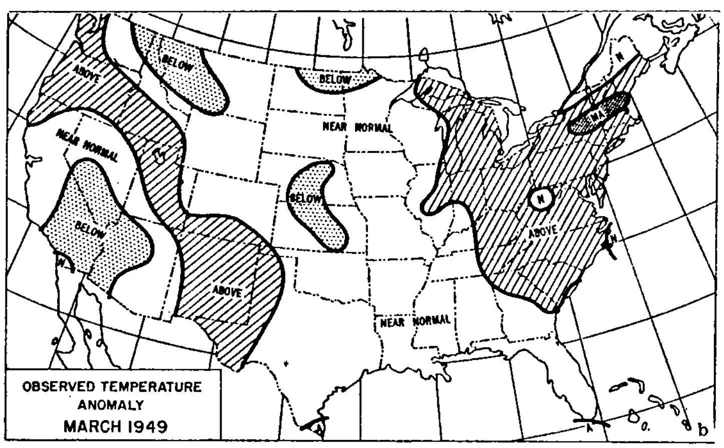
a. 700-mb. chart. Contours at 200-feet intervals are shown by solid thin lines, 700-mb. height departure from normal at 100-foot intervals by dashed lines with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Heavy arrowhead curve shows vorticity trajectory. Inset: Solid curve shows observed geostrophic zonal wind speed components in meters per second for the Western Hemisphere from 20° to 90° N. latitude; dashed line represents normal wind profile.

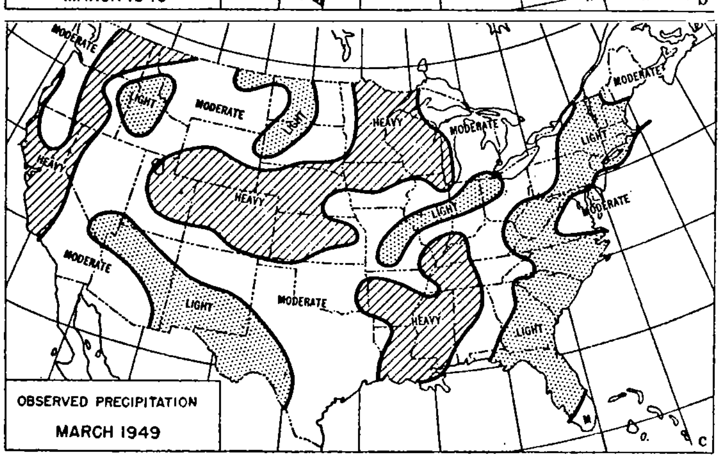
b. Surface temperature anomaly. The classes above, below, and near normal occur on the average one-fourth of the time, while much above and much below each occur normally one-eighth of the time.

c. Precipitation anomaly. The classes light, moderate, and heavy occur on the average one-third of the time and therefore have equal probability of occurrence.

d. Thickness anomaly for the layer between 1,000- and 700-mbs. Isopleths are drawn at 100-foot intervals with the zero isopleth heavier, and centers are labeled in tens of feet. Negative values are shaded.







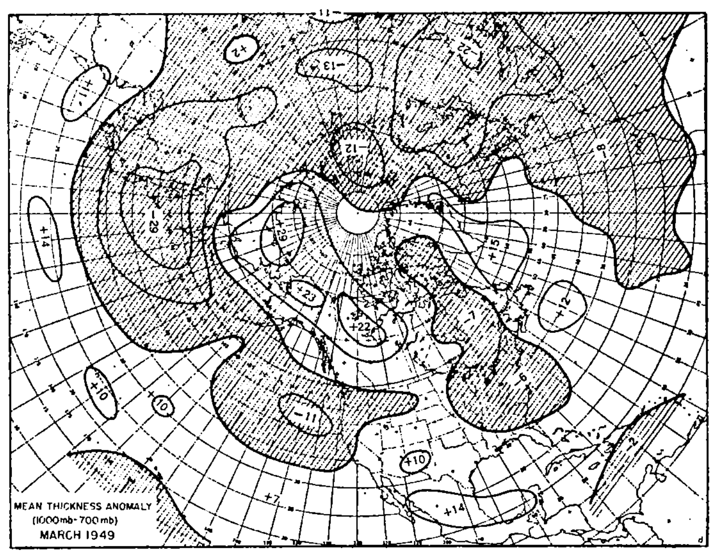


Figure 11.—Monthly mean charts for March 1949.

a. 700-mb. chart. Contours at 200-foot intervals are shown by solid thin lines' 700-mb. height departure from normal at 100-foot intervals by dashed lines with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Inset: Solid curve shows observed geostrophic zonal wind speed components in meters per second for the Western Hemisphere for 20° to 90° N. latitude; dashed line represents normal wind profile.

b. Surface temperature anomaly. The classes above, below, and near normal occur on the average one-fourth of the time, while much above and much below each occur normally one-eighth of the time.

c. Precipitation anomaly. The classes light, moderate, and heavy occur on the average one-third of the time and therefore have equal probability of occurrence.

d. Thickness anomaly for the layer between 1,000- and 700-mbs. Isopleths are drawn at 100-foot intervals with the zero isopleth heavier, and centers are labeled in tens of feet. Negative values are shaded.

its normal position and 10° north of its position during the preceding two months. This was accompanied by the cutting off of three separate cold low-latitude troughs with closed negative anomaly centers spaced only 50°–70° apart near the Hawaiian Islands, southern California, and the central Atlantic, in a manner analogous to the cut-off process on daily maps described by Palmén [25] and others [22]; at high latitudes the wave length increased to about 120° and the number of waves around the entire northern hemisphere was reduced to only 3. Consistent with the vorticity trajectories of the preceding month, the Pacific trough deepened and ended its long-period retrogression in the north, the Pacific ridge intensified and moved east to the Alaskan coast, the trough-ridge system in the United States increased greatly in amplitude, and a zone of confluence developed near James Bay. All these features of the January circulation patterns are remarkably similar to the schematic flow pattern postulated by Namias [15, fig. 11B] to follow strong deepening of a trough located in almost the same position as the Eurasian trough during December 1948.

While these events were occurring, the lower portion of the Pacific trough retrograded to a position just off the Japanese coast. As a result the wave length between it and the California trough became excessive and a new low-latitude trough in the westerlies developed in the Hawaiian region, in a position agreeing with the vorticity trajectory computed at low latitudes in the western Pacific (fig. 9a). Warm air advection ahead of this Hawaiian trough probably contributed to the increase of heights in the eastern Pacific and western Canada observed during January, which in turn, produced northeasterly wind components relative to normal in the western United States at both the surface and aloft. This flow steered polar anticyclones from Alaska and the Yukon, where the air was abnormally cold, as shown by the mean thickness anomaly for December (fig. 8d) and January (fig. 9d), southward into the Great Basin, as illustrated by the anticyclone track of figure 3b, and helped produce the severe January weather experienced by the western United States.

The development of the Hawaiian trough also led to the establishment of a zone of confluence in January in the Gulf of Alaska between warm southerly flow from the Hawaiian Islands and cooler southwesterly flow from the western Pacific. Confluence was even more marked in eastern North America, where the cyclonically curved northwesterly current was bringing cold air from Alaska alongside warm air from the anticyclonically curved southwesterly flow from Mexico. These confluence processes may have been associated with the appearance of the jet stream between 50° and 55° N. latitude and the cutting off of the low-latitude troughs in the western United States and central Atlantic. They were also probably related to the development of an extremely fast band of westerlies across the North Atlantic and Eurasia and to a marked decrease in the amplitude of the trough-ridge system in Eurasia. In figure 9a, the vorticity trajectory computed in the southwesterly flow in Siberia spreads the flattening process eastward and denotes retrogression and decrease in amplitude for the principal circulation features of the Pacific and North America, at least at higher latitudes.

This is essentially what happened during the next month, as shown by the 700-mb. chart for February, figure 10a. At the same time a secondary jet stream began to emerge between 40° and 45° N. latitude, 10° south of the decaying primary jet between 50° and 55° N. As the westerlies spread south the closed low-latitude lows (relative to normal) of the preceding month opened to the north in both the Atlantic and the United States, while the Hawaiian trough disappeared completely. This trough disappearance left an excessive wave length across the Pacific at low latitudes, in response to which the California trough also began to retrograde, in accordance with the indication of the vorticity trajectory computed in the central Pacific on the February chart. As a result of flattening and retrogression, cyclonic curvature and below-normal heights replaced anticyclonic curvature and above-normal heights in the Gulf of Alaska and western Canada, and westerly flow relative-to-normal and maritime conditions replaced northeasterly flow relative-to-normal and continental conditions in most of the western United States (compare temperature and precipitation anomalies for months of January and February, figs. 9 and 10, parts b and c).

The weather continued to moderate in March, when above-normal temperatures occurred in the western United States (fig. 11b) and western Canada (fig. 11d) for the first time in 5 months. This warming was associated with continued southward shift of the westerlies, with a jet stream appearing between 30° and 35° N. latitude, continued retrogression of the California trough to a position about 10° off the coast, and continued weakening of the Pacific ridge (fig. 11a). These processes of flattening and retrogression, which were initiated in Eurasia in January and which affected the circulation in the Pacific and western North America in February, had profound effects upon the circulation pattern of eastern North America, the Atlantic, and Eurasia in March, when the positive anomaly in the East Coast ridge almost disappeared, the Atlantic trough retrograded to a position close to that given by the vorticity trajectory computed in the Pacific in February, the positive anomaly in Europe appeared in the central Atlantic, and the Russian trough moved west from the Urals to the Balkans and Poland. These changes in circulation produced lower heights, more northerly flow, and cooler temperatures in Europe and the eastern United States, and the weather returned to near normal in many parts of the world.

Conclusion

In conclusion it should be emphasized that the abnormalities of this winter's weather in the United States were intimately related to the circulation pattern of the entire northern Hemisphere. In this article, as in previous papers by Namias [1 and 15], an attempt was made to demonstrate that changes in the circulation in one part of the hemisphere greatly affect the circulation in other parts of the hemisphere. During this winter most of these changes proceeded downstream in qualitative agreement with simple wave length and vorticity principles;[4] in other years they appeared to be transmitted in a much

[4] An empirical study of the applicability of wave length and vorticity considerations to the 700-mb. monthly mean maps observed during the last 15 years is now being conducted as a research project of the Extended Forecast Section, U. S. Weather Bureau.

more complicated fashion and occasionally in an upstream direction through blocking action (Namias [15]; Elliot and Smith [26]). It was previously shown (Namias and Clapp [18]; Klein and Winston [27]; Hess and Wagner [28]) that energy is frequently transferred downstream at a rate considerably greater than the speed of individual air particles. In this paper evidence was presented that the effects of circulation changes on monthly mean maps may sometimes be transmitted downstream much more slowly than the speed of individual air particles. A similar phenomenon was recently noted by Elliott and Smith [26] for blocking cases studied with three-day mean maps. These processes of non-advective transport or dispersion of energy were discussed theoretically for simple atmospheric models with the aid of the group velocity concept by Rossby [29] and Yeh [30]. A complete explanation of the complex mechanism by means of which large-scale disturbances are intiated and transmitted in the observed atmosphere will probably require many more years of study of the circulation itself and of extra-terrestrial influences as well.

REFERENCES

1. J. Namias, "Characteristics of the General Circulation over the Northern Hemisphere During the Abnormal Winter 1946–47," *Monthly Weather Review*, vol. 75, No. 8, August 1947, pp. 145–152.
2. H. C. Willett, "Patterns of World Weather Changes," *Transactions, American Geophysical Union*, vol. 29, No. 6, December 1948, pp. 803–809.
3. S. B. Solot and W. H. Haggard, "Relationships between Large-Scale Atmospheric Flow Patterns and Hawaiian Precipitation," *Transactions, American Geophysical Union*, vol. 29, No. 6, December 1948, pp. 796–802.
4. Meteorology Department, California Institute of Technology, *Synoptic Weather Types of North America*, C. I. T., Pasadena, California, December 1943.
5. E. H. Bowie, and R. H. Weightman, "Types of Anticyclones of the United States and Their Average Movements," *Monthly Weather Review Supplement No. 4*, 1917.
6. J. Namias and K. E. Smith, *Normal Distribution of Pressure at the 10,000-Foot Level over the Northern Hemisphere*, Extended Forecast Section, U. S. Weather Bureau, Washington, D. C., 1944.
7. J. Namias, "Experiment in the Preparation of Monthly Forecasts by Trend Methods," Extended Forecast Section, U. S. Weather Bureau, Washington, D. C., 1942 (Unpublished).
8. D. E. Martin, "Objective Procedure for Preparing Long Range Temperature Forecasts," Extended Forecast Section, U. S. Weather Bureau, Washington, D. C., 1949 (Unpublished).
9. W. H. Klein, "Winter Precipitation as Related to the 700-mb. Circulation," *Bulletin, American Meteorological Society*, vol. 29, No. 9, November 1948, pp. 439–453.
10. W. M. Rowe, "Relationship between Surface Temperature and Mean Virtual Temperature in the Lower Troposphere," U. S. Weather Bureau *Research Paper No. 22*, 1944.
11. K. E. Smith, "Five-Day Precipitation Pattern in the United States in Relation to Surface and Upper Air Mean Charts," Master's thesis at Department of Meteorology, Massachusetts Institute of Technology, 1941 (Unpublished).
12. B. Ratner, *Upper Air Average Values of Temperature, Pressure and Relative Humidity over the United States and Alaska*, Climate and Crop Weather Division, U. S. Weather Bureau, Washington, D. C., 1945. (Reprint in press as Weather Bureau Technical Paper No. 6).
13. C.-G. Rossby, and H. C. Willett, "The Circulation of the Upper Troposphere and Lower Stratosphere," *Science*, vol. 108 No. 2815, December 10, 1948, pp. 643–652.
14. P. F. Clapp, "An Outline of a Theoretical Approach to the Problem of the Application of Physical Theory to Mean Charts," Extended Forecast Section, U. S. Weather Bureau, Washington, D. C., 1946 (Unpublished).
15. J. Namias, "Evolution of Monthly Mean Circulation and Weather Patterns," *Transactions, American Geophysical Union*, vol. 29, No. 6, December 1948, pp. 777–788.
16. C.-G. Rossby, "Relation between Variations in the Intensity of the Zonal Circulation of the Atmosphere and the Displacements of the Semi-permanent Centers of Action," *Journal of Marine Research*, vol. 2, No. 1, 1939, pp. 38–55.
17. C.-G. Rossby, "Forecasting of Flow Patterns in the Free Atmosphere by a Trajectory Method," Appendix to: *Basic Principles of Weather Forecasting* by V. P. Starr, New York, Harper and Brothers, 1942, pp. 268–284.
18. J. Namias, and P. F. Clapp, "Studies of the Motion and Development of Long Waves in the Westerlies," *Journal of Meteorology*, vol. 1, Nos. 3 and 4, December 1944, pp. 57–77.
19. R. S. Bortman, "Empirical Corrections to Constant Absolute Vorticity Trajectories," *Transactions, American Geophysical Union*, vol. 29, No. 3, June 1948, pp. 324–330.
20. J. Namias and P. F. Clapp, "Normal Fields of Convergence and Divergence at the 10,000-foot Level," *Journal of Meteorology*, vol. 3, No. 1, March 1946, pp. 14–22.
21. G. P. Cressman, "On the Forecasting of Long Waves in the Upper Westerlies," *Journal of Meteorology*, vol. 5, No. 2, April 1948, pp. 44–57.
22. Staff Members of the Department of Meteorology of the University of Chicago, "On the General Circulation of the Atmosphere in Middle Latitudes," *Bulletin, American Meteorological Society*, vol. 28, No. 6, June 1947, pp. 255–280.
23. R. S. Bortman, "The Interrelationship of Wavelength, Amplitude, and Wind Speed in Upper Air Flow Patterns," Extended Forecast Section, U. S. Weather Bureau, Washington, D. C., 1949 (Unpublished).
24. J. Namias, "Physical Nature of Some Fluctuations in the Speed of the Zonal Circulation," *Journal of Meteorology*, vol. 4, No. 4, August 1947, pp. 125–133.
25. E. Palmén, "Origin and Structure of High-Level Cyclones South of the Maximum Westerlies," *Tellus*, vol. 1, No. 1, February 1949, pp. 22–31.

26. R. D. Elliott and T. B. Smith, "A Study of the Effects of Large Blocking Highs on the General Circulation in the Northern-Hemisphere Westerlies," *Journal of Meteorology*, vol. 6, No. 2, April 1949, pp. 67–85.

27. W. H. Klein and J. S. Winston, "The Path of the Atlantic Hurricane of September 1947 in Relation to the Hemispheric Circulation," *Bulletin, American Meteorological Society*, vol. 28, No. 10, December 1947, pp. 447–452.

28. S. L. Hess and H. Wagner, "Atmospheric Waves in the Northwestern United States," *Journal of Meteorology*, vol. 5, No. 1, February 1948, pp. 1–19.

29. C.-G. Rossby, "On the Propagation of Frequencies and Energy in Certain Types of Oceanic and Atmospheric Waves," *Journal of Meteorology*, vol. 2, No. 4, December 1945, pp. 187–204.

30. T.-C. Yeh, "On Energy Dispersion in the Atmosphere," *Journal of Meteorology*, vol. 6, No. 1, February 1949, pp. 1–16.